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Details of mixing and placing as well as condition surveys of the pavement are discussed. Air pollution measurements and laboratory analysis of the mixtures are also discussed. The downwind dust from the plant was the same for cold mix as the hot mix operation. The particulate and aerosol emissions of the cold mix were less than hot mix operations. However, pavement performance has not been equivalent to adjacent hot mix pavement overlays.

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HIGHWAY RESEARCH REPORT

COLD ASPHALT CONCRETE OVERLAY

INTERIM REPORT

72-53

STATE OF CALIFORNIA

BUSINESS AND TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

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CA-HY-MR-3542-1-72-48

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DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

Interim Report
M&R 653542-1
19-953106
FHA G-2-8
December 1972

Mr. Robert J. Datel
State Highway Engineer

Dear Sir:

Submitted herewith is an interim research report titled:

COLD ASPHALT CONCRETE OVERLAY

Report Prepared by

Thomas Scrimsher,
Melvin H. Johnson
and
George B. Sherman

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

ACKNOWLEDGMENTS

Mr. Leigh S. Spickelmire and Mr. Paul I. Wagner of the California Division of Highways, Headquarters Construction and Design Departments, respectively, served as advisors on this project. Mr. Spickelmire is also acknowledged for his thorough review and commentary of the draft of this report.

The authors wish to acknowledge the assistance of Mr. Loren M. Barnett, District Operations Engineer; Mr. Hal S. Lee, District Construction Engineer; Mr. Thomas L. Rundle, District Materials Engineer; Mr. James O. Erwin, Resident Engineer; and other members of the California Division of Highways' District 08 staff. Mr. Lee was particularily instrumental in the establishment of this project.

The authors wish to acknowledge the cooperation and active participation of Mr. Reed Sprinkle, President of the Fontana Paving Company; and Mr. W. J. Kari, Mr. L. D. Coyne and Mr. D. C. Fink of the Chevron Asphalt Company.

The authors appreciate the contributions of Mr. John B. Skog, Mr. Earl C. Shirley and Mr. Kenneth O. Pinkerman of the Environmental Improvement Section of the Materials and Research Department. They wrote the discussion on air pollution measurements.

This work was performed as part of a research project conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration, under item No. G-2-8.

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INTRODUCTION

Over the years, an obvious contributor to air pollution has been hot asphalt mixture plants. Contaminants are placed in the air from the burning of some fuels used for heating and drying aggregate, from dust produced by dry aggregate prior to mixing with asphalt, from the heating and mixing of the asphalt, from the completed mixture when it is dropped into a truck from a pug mill, and from the mixture during the spreading operation. Therefore, the California Division of Highways initiated a project to determine, by field trial and evaluation, if cold mixed asphalt concrete can reduce pollution and, at the same time, provide a durable asphalt concrete pavement.

The first project studied was a one-mile test section of a 1-inch cold mixed asphalt concrete overlay. This section is located on Highway 30, near the City of Fontana in District 08 (Exhibit 1). It was constructed in September 1971. Two types of cold mixture, "open graded" and "dense graded", were placed so that there was approximately 1/2-mile of each as shown in Exhibit 2. The mixture designated as dense graded incorporated 1/2-inch maximum aggregate and CSS-1h emulsion. The mixture designated as open graded had 3/8 x #6 aggregate and CMS-2h emulsion. Experimental work was performed under Contract Change Order No. 3, Contract No. 08-151824. Asphalt mixtures were designed by the Chevron Asphalt Company and the Fontana Paving Company did the paving. This report discusses the construction of this experimental section and the first year's service life.

CONCLUSIONS

Placement and performance for the first year of both mixtures were observed and the following conclusions drawn:

1. Performance of experimental mixtures has not been equivalent to hot mix placed adjacent to the experimental sections. The open graded mixture is not performing satisfactorily due to cracking and raveling. Similar defects are apparent in the dense graded section. However, a completely valid conclusion as to the performance of the dense graded mixture cannot be made due to damage caused during construction by the premature application of a fog seal.

2. Measured particulate and aerosol emissions from the cold mix paving operation were less than a hot mix paving operation and no visible emissions were noted in the mixing and placing of these cold mixes. However, the downwind dust from the plant was the same for both cases. Considerable dust was emitted during placement of the sand choker required for the open graded mixture.

3. Variation in emulsion content of the open graded mix and moisture content of the dense graded mix, has not resulted in visual differences in pavement surface condition after one year of service life.

4. A method of design to determine optimum emulsion content has not yet been perfected and during construction great reliance is placed on experienced field personnel for final adjustments.

5. Selection of emulsion type is largely dependent on gradation and other physical properties of the aggregate.

6. Dense graded mixtures should not have a fog seal applied too soon after placing.

IMPLEMENTATION

This report discusses the construction and first year's service life of the initial project studied in this research effort. Therefore, it is too early for implementation other than to apply the findings of this project to additional projects. Implementation recommendations will be presented in a future interim report or in the final report for this entire research project.

PROJECT DESCRIPTION

The test section was one mile of a 1-inch cold mix overlay on Highway 30 in San Bernardino County in District 08. Highway 30 is a 2-lane asphalt concrete facility running east and west and carrying approximately 4000 vehicles per day, 17 percent of which are trucks. Traffic on the highway is estimated to average 50 to 65 miles per hour.

At the time this test section was selected, the test section was part of a resurfacing contract on Highway 30.

Prior to this resurfacing, Highway 30 had been widened 2 feet on each side for additional shoulder area. These areas were cracked and slightly depressed from the regular traveled way, resulting in a rather rough riding section near the edge. Therefore, the new construction called for resurfacing the entire width including the 2 foot shoulders. The regular traveled way had only occasional cracking and appeared in very good condition.

Mr. Reed Sprinkle, President of Fontana Paving Company, offered to participate in a study to determine if cold emulsion mix could be substituted for hot mixed asphalt concrete as a means of meeting very restrictive air pollution regulations without the capital investment necessary for the latter.

The location between Post Miles 11 and 12, Route 30, referred to locally as Highland Avenue, was selected as the test section. This location intersected only one street (East Avenue), and that street carried very little traffic.

This area has an average rainfall of about 15-inches per year. Ambient temperatures range from 115°F in the summer to a low of 25°F during the winter. Most of the project was shaded by tall Eucalyptus trees located within 20 feet of the south edge of the roadway. Drainage ditches are located along both sides of the roadway and the adjacent farmland consists of abandoned citrus orchards or uncultivated fields.

MATERIALS

Aggregate as supplied by Fontana Paving Company was, in general, an all-crushed stream bed gravel of good sound quality. The gradings selected for use were: (1) a dense grading conforming to the tolerances for California's 1/2-inch medium grading and (2) an open grading conforming to the tolerances for 3/8 x #6 seal coat screenings (Table 1).

Sand used as a choker for the open graded mixture was obtained from the No. 1 bin (-#8 fraction) at the plant.

Emulsions were supplied by the Chevron Oil Company and were CMS-2h and CSS-1h. CMS-2h is a cationic medium setting type emulsion containing a stabilizing additive and having a base asphalt with a penetration between 40 and 50. In addition, the emulsion contains an oil distillate to facilitate mixing. CSS-1h is a cationic slow setting type emulsion having a base asphalt with a penetration between 60 and 70.

PLANT OPERATIONS

A conventional 3,000 lb. Madsen Asphalt Plant (Figure 1) was used to prepare the mixtures. The aggregates were not dried although they were fed to the plant through the dryer. (There was no firing of the dryer.) The aggregates were then screened with the normal screens on the plant utilized for hot mixes. (Due to the dryness of the stockpiled material, which essentially was all crushed, very little clogging of the screens was noted.) The screens were left in place merely for operational convenience of this particular project and were not a requirement.

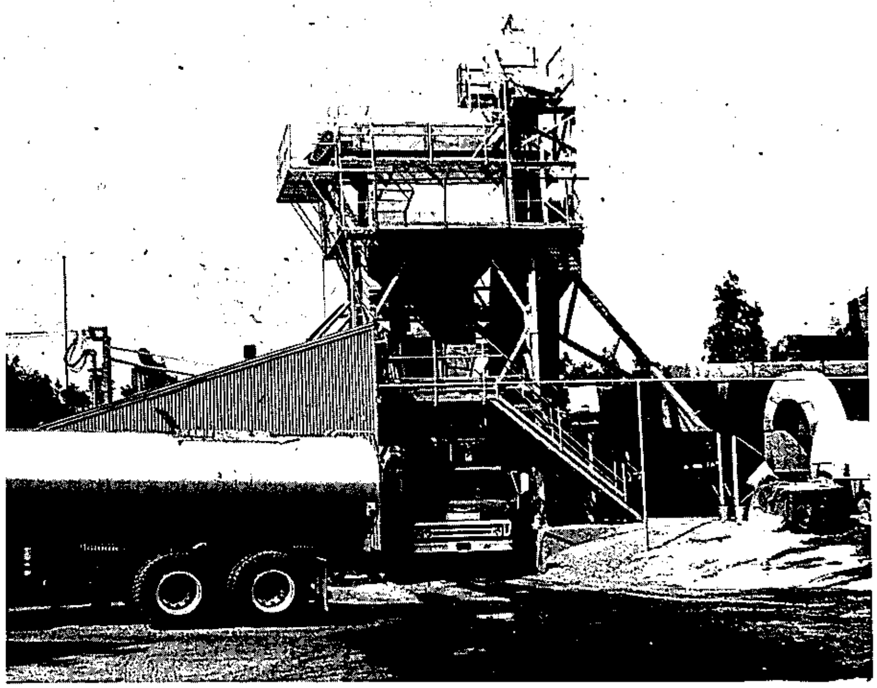

Figure 1 - Mixing Plant

The emulsion was pumped from the truck and trailer unit used for transport (Figure 2). With the use of a flexible hose, connections were made to route the emulsion to the plant, via the plant pump, and return to the truck and trailer unit, thus setting up a system of continuous circulation. With the use of a three-way valve emulsion was metered into the batch as required. A supply of water for premixing with dense graded material was also made available and it was metered as needed through the regular plant asphalt meter.

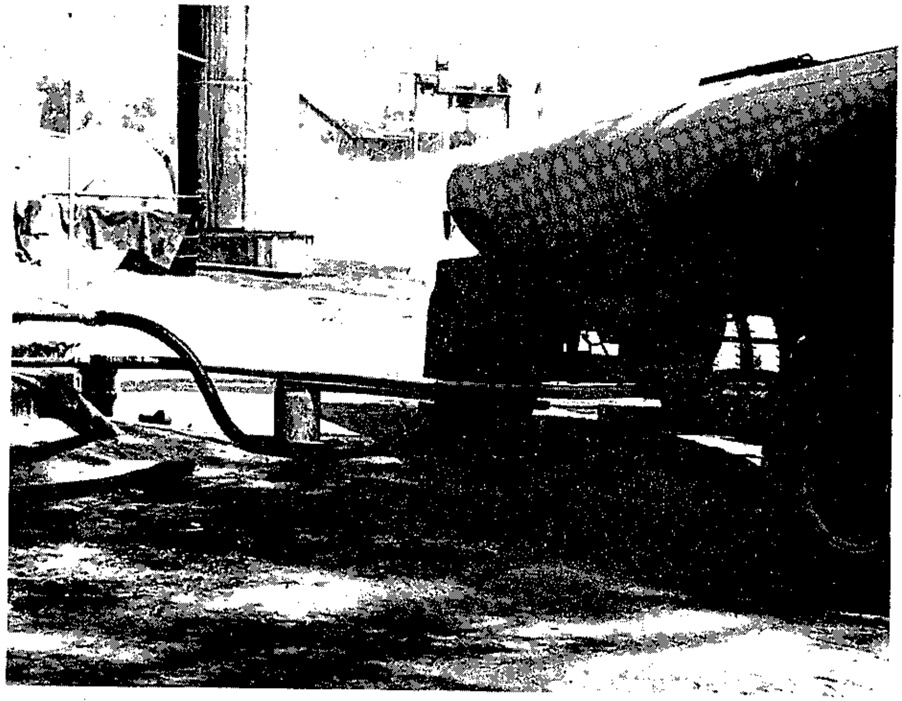

Figure 2 - Emulsion Fed to Plant From Truck

Chevron Asphalt Company designed the mixes in the laboratory. However, in order to determine the proper percentage of emulsion and water that would actually be required, trial batches were mixed at the jobsite. These batches were placed on a plant access road (Lime Avenue). From these trials it was learned that mixing time was extremely critical. Excessive mixing with either grading caused almost complete stripping of the emulsion from the aggregate. Insufficient mixing resulted in a poor coating. The permissible mixing time appeared to be 12 - 15 seconds for the open graded mix and 15 - 20 seconds for the dense graded mix. These mixing times were carefully adhered to during actual production and as a result only two batches were discarded due to poor mixing.

The procedure with the open graded mix was to batch out the aggregate, meter in the CMS-2h emulsion, mix together for 12 - 15 seconds and dump into the haul truck. Emulsion content was either 6, 6-1/2 or 7 percent as shown in Exhibit 2. The size of each batch was 2,500 lbs.

Because only one bin of aggregate (3/8 x #6) was used for the open graded mix, it became necessary to frequently dump the sand bin which was constantly being fed and not used. (It had to be emptied about every 8 loads of mix.) The first sand load dumped into the truck raised an undesirable cloud of dust. Thereafter, the following process for unloading the bin was successfully implemented to control dust:

1. Deposit 2,000 lbs. of sand into pug mill.

2. Add approximately 6 percent water (by weight).

3. Mix 10 or 15 seconds.

4. Dump into empty truck.

5. Repeat until sand bin is empty.

However, a problem was created. Quantities of the moistened sand would cling to portions of the pug mill and be introduced into subsequent batches of emulsion mix. The first batch would appear to be very deficient in asphalt and have very little color. The second batch would appear not quite as deficient. The third and succeeding batches appeared quite normal. The plant man felt that an allowance of additional emulsion should be made on the first two batches to correct for the wet sand and this was accomplished by using his own judgment and experience after the first few batches.

The procedure followed for the dense graded mix consisted of batching the aggregate, adding a metered amount of water, mixing for 5 - 10 seconds, adding a metered amount of emulsion and mixing for 15 - 20 seconds and dumping into the truck. The size of each batch was 2,500 lbs. The aggregate used in the dense graded mix, although not completely dry (around 0.5 percent moisture), was quite consistent during the operations; however, moisture contents ranging from 5.6 to 6.4 percent were tried during the day for experimental purposes. The emulsion content was 8 percent except for one small area where it was 8-1/2 percent. Exhibit 2 indicates the placement of the various mixtures in the street.

STREET OPERATIONS

After a haul of approximately 7 miles, the mixtures were placed with ambient temperatures ranging from 70° to 90°F under clear skies (Table 2). The paving width was 10 feet (0.08 feet thick) and three adjacent passes were made for complete coverage of the 30 foot width.

Prior to paving, 1,000 feet of tack coat was placed in the lane to be paved. A CSS-1h emulsion diluted three parts emulsion to one part water was used. This application gave an amount of emulsion equal to an asphalt residue of .05 gal. per sq. yd.

Equipment on the job consisted of a Barber Greene Paver, two 12-ton tandem steel rollers and a 10-ton pneumatic roller with 34 psi tire pressure.

Paving started at 8 a.m. at Post Mile 11, in the westbound lane, and proceeded easterly toward Post Mile 12. The paver was loaded by end dumping into the hopper (Figure 3). Open graded mixture was placed first and it started from and abutted a 1/2 inch dense graded conventional hot mix that had been placed the previous day.

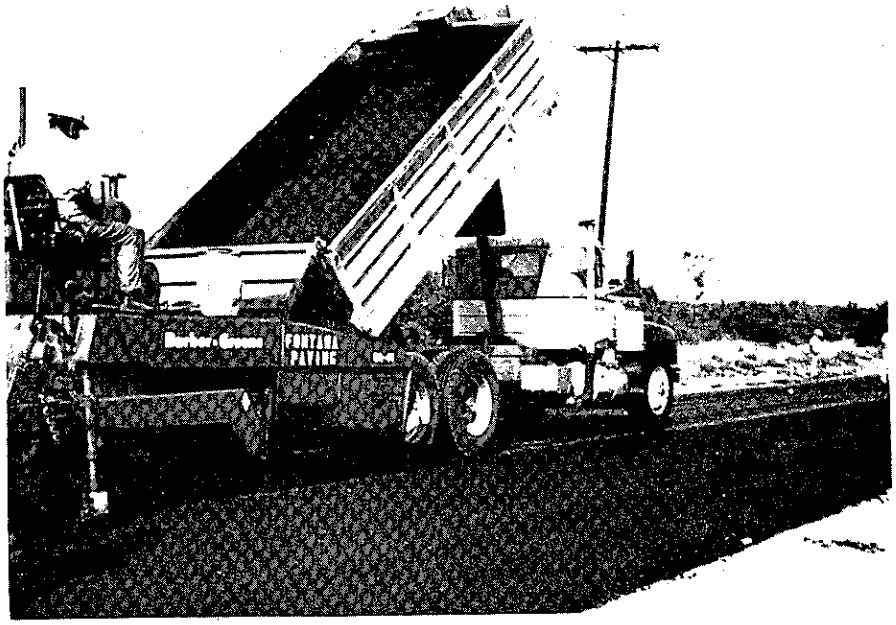

Figure 3 - Open Graded Paving Operation

Construction sequence for the open graded mix was (a) placement of the mixture, (b) breakdown rolling immediately with a steel tandem roller - 1 coverage (Figure 4), (c) application of a sand choker, (d) rolling with a steel tandem roller - 1 coverage, (e) rolling with a pneumatic roller - 2 to 3 coverages (Figure 5), and (f) open to traffic.

Figure 4 - Breakdown Rolling of Open Graded Mix

Figure 5 - Pneumatic Rolling of Open Graded Mix

The open graded mixture appeared quite black immediately upon placement; however, some runoff of emulsion was noted on the shoulders as paving progressed (Figure 6). It is felt that the runoff may have actually been caused by the tack coat. The mixture gave the appearance of a good, well coated, conventional, open graded mixture (see Exhibit 3). A sand choker was applied to stop pickup from the rolling operations. The roller was equipped with water to wet the wheels; however, there was still some pickup evident until a detergent was added to the water. Pickup was then minimized; nevertheless, the sand choker was still used on all open graded placed.

Figure 6 - Shoulder Runoff

Sand choker was spread through a sand spreader (Figure 7). The first sand choker applied was seen to nearly hide the mixture with an estimated cover of 1/8-inch and was felt to be excessive. Subsequent amounts (after the first 100 feet of the first paved lane) were reduced so as to give the appearance of a lightly scattered sand effect.

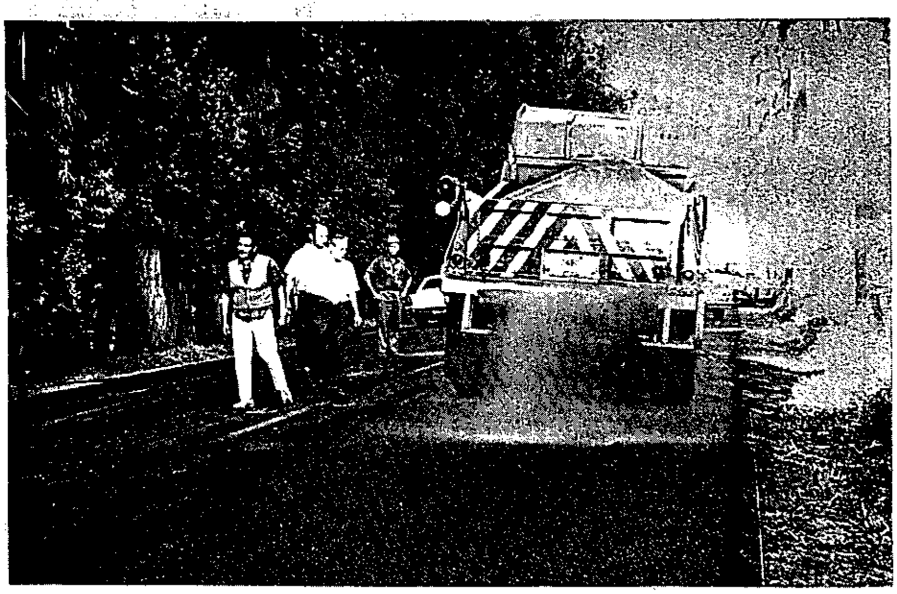

Figure 7 - Applying Sand Choker

All open graded mixture was placed before placing the dense graded mixture.

Dense graded mixture was placed using the following construction sequence: (a) placement of the mixture, (b) rolling immediately with a steel tandem roller - 2 coverages. The dense graded mixture did not have a sand choker applied. This mixture after placing appeared to take longer to cure and several wet spots could be detected (Figure 8). After 4 to 6 hours the entire surface was covered by a film of free water.

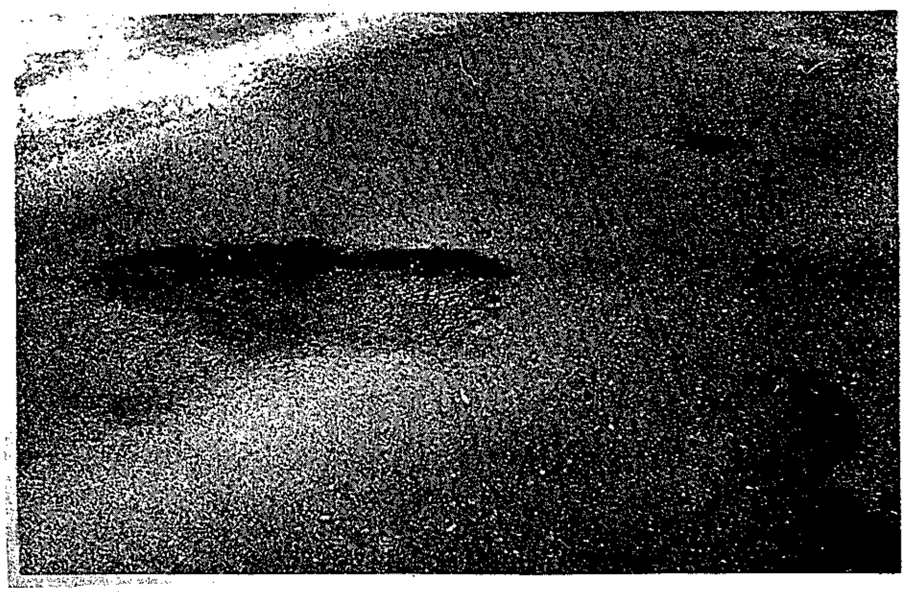

Figure 8 - Wet Spots Appearing in Dense Graded Surfacing

During paving traffic was routed adjacent to the operation by a pilot car. Traffic was allowed on the first open graded section 45 minutes after placing. No visible rutting or distortion was apparent. Traffic was allowed on the dense graded mixture about 1 hour after placing. Slight damage was noted in spots on the dense graded surface where traffic had to turn across lanes to avoid construction (Figure 9). Some heavy trucks, which had to stop due to traffic control, left crescent shaped slippage cracks in the dense graded mat when they started up again.

Figure 9 - Raveling in Dense Graded Due to Turning
4 Hours After Construction

AIR POLLUTION MEASUREMENTS

The type of hot plant used on this project and its related stockpiles posed a difficult problem in comparing the hot and cold mixes. Downwind dust load from the stockpiles and plant was very high. Aggregate was fed to the pug mill dry in both cases. No measurable difference in downwind airborne dust from the plant was found in comparing the hot mix and cold mix operations. See Table 3 for concentration measurements.

Differences between hot and cold mix paving operations were:

1. There were no visible emissions produced when dropping a cold mix batch into the truck.

2. There were no products of combustion from the plant stack as the dryer was not operating.

3. There were no visible emissions created in the transfer of cold mixes from the truck to the paver or from the paver to the street.

Particulate and aerosol emissions are created by hot mix asphalt paving operations in each of these situations.

Application of the choker course to the open graded cold mix caused a local dust problem downwind from the roadway. At night dust raised from the choker course by traffic reduced visibility.

PAVEMENT CONDITION AFTER 24 HOURS

The first section of open graded mix had noticeable surface raveling (Exhibit 3) and two or three areas were raveled through to the overlayed surface. Subsequent sections of this mixture showed less severe raveling. It was felt that raveling in the first section was due, at least in part, to placing the sand choker too early, which retarded curing and resulted in a lack of surface cohesion. Raveling was generally confined to the wheel track areas.

The dense graded mixture also showed a slight amount of raveling after 24 hours (Exhibit 4) and there was visual evidence the mixture had not cured completely. A 2-foot section near each edge of pavement appeared brownish compared to the rest of the pavement, which indicated the asphalt still was emulsified (Figure 10).

Figure 10 - Indication of Insufficient Cure in Dense Graded Mix

The wheel track areas appeared black and cured; however, this was only a surface condition. The fact that this area was not sufficiently cured in depth was confirmed a few hours later when a fog seal was applied consisting of CSS-1h emulsion diluted three parts emulsion to one part water and applied to obtain a theoretical 0.10 gal. per sq. yd. residue. A short section was not fog sealed for comparative purposes. Traffic was allowed over both areas immediately and, as the emulsion in the sealed section began to break, it stuck to both tires and surfacing. The results were serious tearing and raveling of the surface (Figure 11). Rocks ripped from the surface were thrown by the tires of fast moving traffic, creating a hazard. Sand was immediately brought out and placed on the surface to blot the emulsion. This was successful and additional raveling and tearing of the surface was arrested.

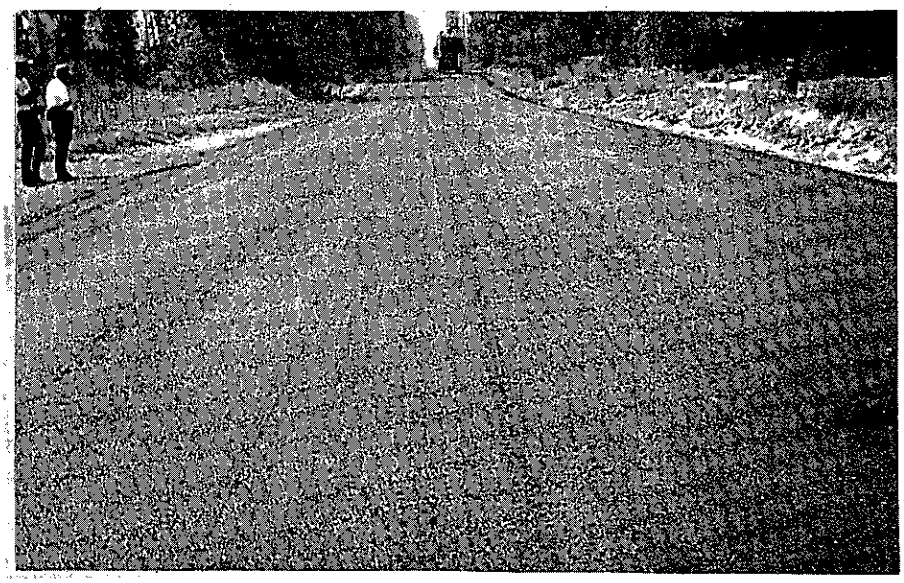

Figure 11 - Dense Graded Surface
1 Hour After Fog Seal

Both mixtures could be displaced by turning one's heel 24-hours after placing. All paving joints were so well knitted that they were hard to detect.

Both experimental surfaces were noticeably rough riding after 24-hours. Apparently traffic had continued to compact the mixtures and as a consequence the surface was not as true a plane as it was after construction rolling.

1. Open Graded Mix

The first pavement condition survey was made after 90-days and the open graded mixture had not deteriorated greatly from initial observations. It was evident, however, that a few aggregate particles were still being displaced and a few areas in the wheel tracks were definitely beginning to indicate raveling. Hairline cracks were easily visible with the pavement wet and were an indication of reflective cracking (Figure 12).

Figure 12 - Reflective Cracks in Wet Open Graded Pavement After 90 Day's Service Life

Edges of the open graded mix were friable and easily displaced. Two or three areas which had severely raveled immediately after construction were patched.

Sections of open graded mix with various emulsion content could not be visually differentiated during the 90-day or any subsequent, condition survey. Riding quality of the open graded mix was considered to be inferior to the adjacent hot mix overlays during all of the inspection trips.

The next field review occurred approximately six months after construction and revealed that the open graded mix had deteriorated. Previously observed hairline reflective cracking had increased and some cracks were spalling (Figures 13 and 14). There was

Figure 13 - Reflective Cracking In Open
Graded Surface

Figure 14 - Raveled Reflective Crack in
Open Graded Surface

some raveling through to the overlayed surface and raveling along the edge of pavement (Figure 15).

Figure 15 - Raveling in Open Graded Surface After Six Months Service Life

The worst areas of raveling were in the westbound lane at the beginning of the open graded overlay, where the heaviest application of choker sand was used. Also, raveling was generally greater in the westbound than in the eastbound lane. Observations of truck traffic indicate that the majority of trucks traveling westbound were loaded and those traveling eastbound were not. This may be a result of the pattern of local commerce and a reason for increased raveling in the westbound lane. The open graded mix was in good condition adjacent to the cold mix dense graded areas. Tracking of the fog seal from the dense graded surface to the open graded surface is a possible explanation for this better performance.

A field survey during the twelfth month of service life revealed that raveling of the open graded mix had somewhat stabilized.

There are areas of raveling extending through the experimental surface but the overall condition was not too bad. However, longitudinal construction joints were visible in certain locations (Figure 16).

Figure 16 - Overall Appearance of Open Graded Mix in a Not Too Raveled Area. Note Longitudinal Construction Joint.

A realistic appraisal of the open graded cold mix material on this project yields the conclusion that the amount of cracking and raveling is not acceptable. There was enough success with this mix though that it can be considered to have potential. The base asphalt used in the CMS emulsion was 40 - 50 penetration. It is possible that greater success might have been realized if a softer base asphalt were used. The mixture was designed to theoretically contain 4.1 to 4.4 percent asphalt residue. In contrast a hot bituminous mixture of the same grading would require 5.5 to 6.0 percent asphalt. The thinner film thickness of the emulsion residue may have been a cause of the hardening of the open graded mix and subsequent raveling. Perhaps, higher emulsion contents would have helped these problems, but drainage of the emulsion from the aggregate was anticipated. Also a fog seal, applied shortly after construction, might have reduced the amount of distress. It was quite evident that a heavy choker sand application increased the amount of raveling and this phase should be carefully controlled in future projects.

2. Dense Graded Mix

The 90-day pavement survey indicated that dense graded mix in the area where fog seal was not applied had substantial surface raveling (Figure 17). The dense graded mix with fog seal also had surface raveling (Figure 18); however, it was difficult to determine whether it had increased in severity. District personnel feel there has been some progression since the first occurrence. A small amount of hairline cracking was also noted.

Figure 17 - Raveling in Dense Graded Surface
(No Fog Seal - 90 Days)

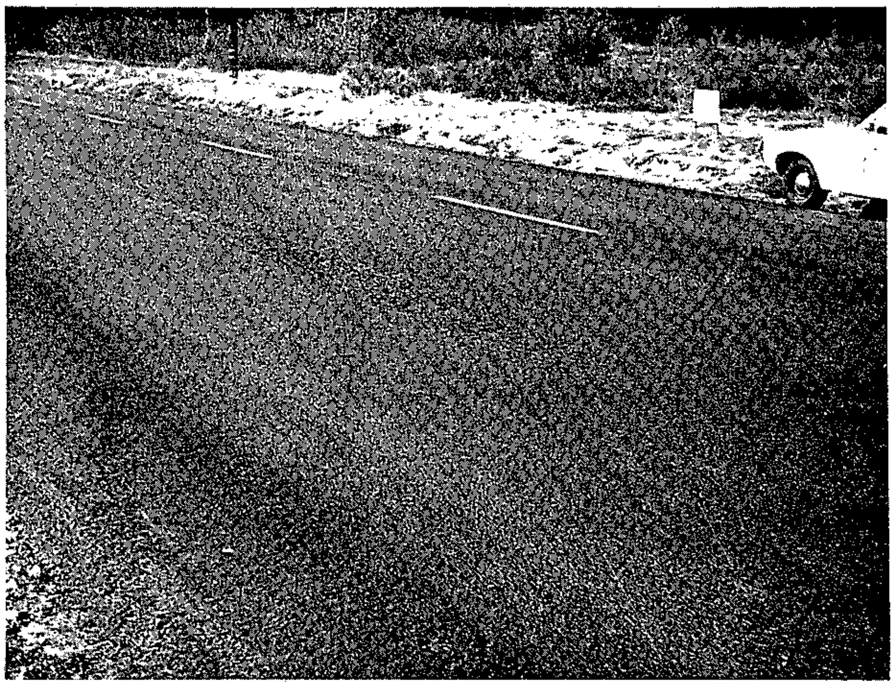

Figure 18 - Raveling in Dense Graded Surface
(Fog Seal - 90 Days)

Edges of the mix were friable and easily displaced with foot pressure as in the case of the open graded mix. Also, some loss of material from the edge at the lanes was noted (Figure 19).

Figure 19 - Friable Shoulders Due to
Lack of Compaction

During the 90-day inspection, and in all following inspections, no visual differences in pavement surface condition were noted between areas with variations in moisture content.

The six month field review revealed that the dense graded mixture, which had been sealed, appeared essentially the same as it did after 90 days. Hairline cracking, previously observed, appeared to have healed and surface raveling had not progressed. Dense graded mixture that was not sealed still showed signs of progressive raveling. This raveling was mostly isolated aggregate pop-out (Figure 20) and was not severe enough to warrant corrective treatment at that time.

An inspection was made during the twelfth month of service and the sealed dense graded surface had generally improved in

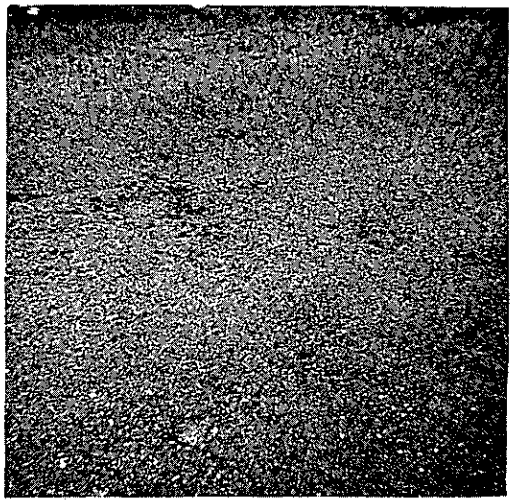

Figure 20 - Isolated Aggregate Pop-outs in Dense Surface (No Fog Seal - Six Months)

appearance (Figure 21). Traffic seemed to have smoothed out

Figure 21 - Overall View of Dense Graded Cold Mix Looking East From Station 26+00

the effects of raveling caused by the original fog seal though some signs still appear and in some areas there is evidence of the longitudinal construction joint (Figure 22). The unsealed area had continued to deteriorate and was definitely in

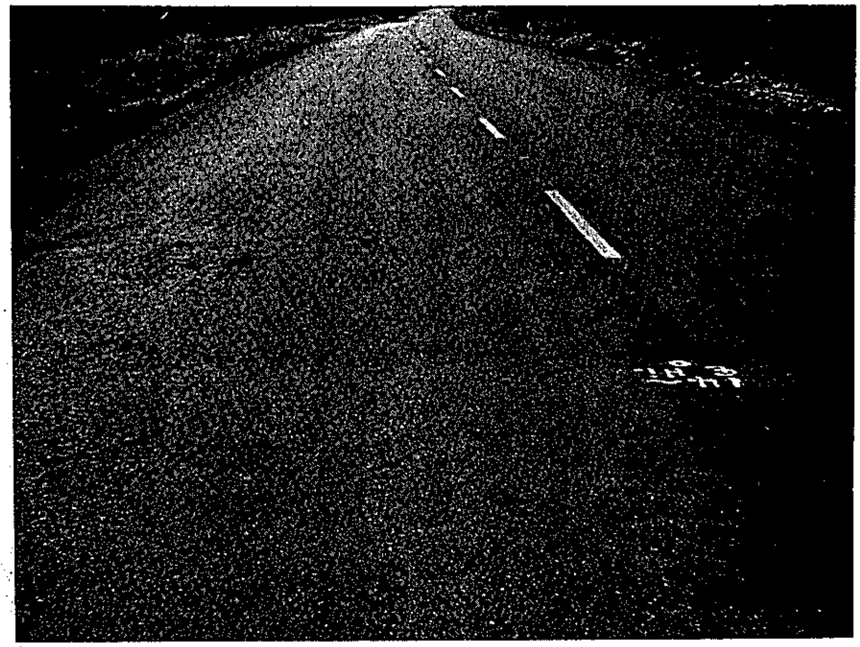

Figure 22 - Evidence of Raveling and Construction Joint in Dense Graded Surface After One Years Service Life

need of a maintenance seal. Crescent shaped slippage cracks, caused by the heavy truck traffic shortly after paving, were still present and in one case the material had raveled through to the overlayed pavement in an area approximately 6-inches in diameter.

Riding quality of the dense graded surface, during all of the inspection, was not considered to be as good as the adjacent sections of hot mix overlay. There was no distinguishable difference between the riding quality of the open and dense graded cold mix surfaces.

It is difficult to give a valid appraisal of the first year's service of the dense graded cold mix material due to the early application of a fog seal and subsequent damage. Observation of the unsealed section definitely indicates that a fog seal is necessary; however, experience with this job proved that it should not be applied until the emulsion is sufficiently cured. It is also evident that traffic should be kept off the dense graded mix for as long as possible to allow proper curing and prevent initial surface damage. However, this is not generally possible, particularily with overlay work. In any case the performance of this cold mix dense graded material is sufficient to warrant additional investigation.

The adjacent hot mix surfacing appeared to be in excellent condition without any indication of distress except for a very minor amount of reflective cracking noticeable during the twelfth month inspection.

SKID RESISTANCE

Skid resistance measurements were obtained at approximately two months, and again at eleven months, after construction. The results are as follows:

Average Skid Number at 40 MPH (SN_{40})

	11/71	8/72
Dense Graded Mix		
(1) No Fog Seal	49	49
(2) One Fog Seal	49	52
(3) Two Fog Seals	33	40
Open Graded Mix	56	53
Adjacent Dense Graded Hot Mix	- -	50

Readings were obtained with a towed trailer skid tester operating in conformance with ASTM Test Method E-274.

It can be seen that the dense graded mix, without a fog seal, and with one fog seal, has good skid resistance; however, these surfaces were badly raveled at the time of testing (Figure 12). This raveling was not acceptable and additional fog seal, which reduced the skid resistance, was necessary. Skid resistance of the dense graded mix with two fog seals did increase to a satisfactory level within the first year. It can also be seen that the adjacent dense graded hot mix had good skid resistance.

The open graded mix not only has good skid resistance, but also has excellent surface drainage characteristics. This is illustrated in Figure 23 which shows that comparison between the open graded surface and the abutting hot mix dense graded surface during a rainstorm. Figure 24 shows the comparison between the cold mixed dense graded and the cold mixed open graded during the same rainstorm.

Figure 23 - Contrast During Rain of Hot Mix Dense in Background, and Cold Mix Open Graded Surfaces.

Figure 24 - Contrast During Rain of Dense (Right-Side), and Open Graded Cold Mix Surfaces.

It is evident that the open graded mix has good potential as a skid resistance treatment with excellent drainage characteristics. It is assumed that the application of a fog seal to reduce cracking and raveling would not materially reduce skid resistance.

necessary; however, experience with this job proved that it should not be applied until the emulsion is sufficiently cured. It is also evident that traffic should be kept off the dense graded mix for as long as possible to allow proper curing and prevent initial surface damage. However, this is not generally possible, particularily with overlay work. In any case the performance of this cold mix dense graded material is sufficient to warrant additional investigation.

The adjacent hot mix surfacing appeared to be in excellent condition without any indication of distress except for a very minor amount of reflective cracking noticeable during the twelfth month inspection.

SKID RESISTANCE

Skid resistance measurements were obtained at approximately two months, and again at eleven months, after construction. The results are as follows:

Average Skid Number at 40 MPH (SN_{40})

	11/71	8/72
Dense Graded Mix		
(1) No Fog Seal	49	49
(2) One Fog Seal	49	52
(3) Two Fog Seals	33	40
Open Graded Mix	56	53
Adjacent Dense Graded Hot Mix	- -	50

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It is evident that the open graded mix has good potential as a skid resistance treatment with excellent drainage characteristics. It is assumed that the application of a fog seal to reduce cracking and raveling would not materially reduce skid resistance.

LABORATORY ANALYSIS OF MIXTURES

Samples of both mixtures were obtained during construction for laboratory testing and the results are presented in Tables 4 and 5 and illustrated graphically in Exhibits 5 through 8. Results of tests made on the recovered asphalt are shown in Table 6.

Seven day recovered asphalt penetration results (Table 6) indicate that the CMS-2h (base asphalt 40-50 pen) had an average recovered penetration of 30 and the CSS-1h (base asphalt 60-70 pen) had an average recovered penetration of 42 after mixing. While this is not as much loss as would be expected in a hot mix process, it does indicate there is a hardening effect in this cold mixing process. One year recovered asphalt test results (Table 6) show that hardening is continuing. The CMS-2h has an average penetration of 18 and the CSS-1h has an average penetration of 21. Some of the one year ductility results for the CMS-2h show a loss of this property. This may be a cause for some of the raveling that has developed in the open graded mix.

In almost all cases the percent of asphalt in samples taken from the paver, at a given station, were less than that in samples taken from the street at the same stations (Exhibit 5). This is probably due to the fact that the paver samples were taken from the top material with some emulsion drainage toward the bottom. After the material went through the paver asphalt contents then generally increased; however, results were erratic in regard to correlation with theoretical asphalt contents. This fact indicates a trend toward nonuniformity in the mixing and placing of cold mix material. Field surveys did not show any difference in performance between locations with different theoretical emulsion contents; but, there are definitely areas with different performance characteristics. Limited laboratory testing indicates that variations in actual asphalt content, caused by nonuniformity of the mixing and paving process, are greater than those theoretically planned for predetermined locations. This may explain the reason for spotty areas of poor performance, particularly in the open graded mix.

Open graded mixes are used only as thin overlays in California and therefore stability is not a prime consideration. Consequently, stability was not analyzed for the cold open graded mixes. Dense graded mixes would be considered for standard pavement structural sections and therefore stability was considered. Analysis of the dense graded stabilometer results (Exhibit 6) requires a consideration of the aggregate grading and nature of the emulsions used in the mix. Another consideration, in analysis of these test results, is the fact that 0 hour tests were made at room temperature and tests after cure were made at 140°F.

The aggregate grading and slow setting emulsion used in the dense graded mix resulted in minimal evaporation during the briquette mixing and compacting operation. Therefore, even though the 0 hour test was made at room temperature, stabilometer values were less than the 4 hour cure specimens tested at 140°F. This is because the high moisture content at 0 hours would lubricate the aggregate, resulting in lower interparticle friction and consequent lower stabilometer values. Additional curing time to 100 hours generally does not increase the stabilometer value.

Analysis of stabilometer values indicates that the dense graded cold mix has fairly uniform values; however, these values average about 10 points less than would be expected with this particular grading in a hot mix asphalt concrete.

When considering cohesiometer test results (Exhibit 7) the grading and type of emulsion used also must be considered. Also it should be remembered that the cohesion test primarily measures tensile strength of the mix.

Open graded test briquettes cured substantially during mixing and compaction procedure. Therefore test results after 4 hours' cure were less than those after 0 hour's cure due to the increase in test temperature. The asphalt binder had a chance to harden during the 100 hour cure period, and consequently cohesion values increased substantially after this curing period.

One would expect cohesion of a dense graded mix to be greater than an open graded mix and this is the case at 0 hour's testing even though the dense graded mix have not completely cured. Additional curing for 4 hours at 140°F increases cohesion of the dense graded mix, in spite of the fact that testing temperature was increased. After 100 hours' cure a strange phenomenon occurs. Cohesion values drop when they would be expected to increase. A possible explanation for this could be that the specimens had a high percentage of moisture and in the process of drying out at 140°F, a detrimental water action occurred which reduced cohesion of the mix. It is possible that a weakening of the bond would not affect the stabilometer values, where interparticle friction is measured, but could lower the tensile strength which is measured by the cohesiometer.

All the cohesion values are lower than would be expected from hot dense graded mix. Of course, the drop in values of the dense graded mix, after 100 hours' cure hinders any real evaluation.

The amount of asphalt binder would have a significant effect on stabilometer and cohesion values. However, in this study the variations were not considered large enough to explain variations in test results.

The final laboratory test is the percent of moisture (Exhibit 8). There is not much to discuss except to say that generally the moisture content decreased as it went from mixer to paver to street. This is what one would expect due to evaporation.

TABLE 1

Aggregate Quality Requirements

1/2" Max. Medium — Referenced in Text as Dense Graded

Sieve	% Passing		Quality Tests		
	As Used	Specifications (Section 39)	Test	Specification	Test Results
3/4		100	L.A. Rattler	50% Max. (After 500 Rev.)	22%
1/2	100	95-100	*K Factor	1.7 Max.	Kc=1.1 Kf=1.0
3/8	80	80-95	Sand Equiv.	45 Min.	66
4	55	55-72			
8	39	38-55			
16	26				
30	19	18-33			
50	12				
100	9				
200	6	4-8			

(Choker Sand)

Sieve	% Passing
4	100
8	93
16	62
30	43
50	30
100	19
200	12

Specific Gravity Retained No. 4 = 2.65
Passing No. 4 = 2.70

*From Centrifuge Kerosene Equivalent Test

3/8 x #6 (Medium Seal Coat) — Referenced in Text as Open Graded

Sieve	% Passing		Quality Tests		
	As Used	Specifications (Section 37)	Test	Specification	Test Results
1/2	100	100	L.A.Rattler	10% Max. (After 100 Rev.)	4%
3/8	99	90-100		40% Max. (After 500 Rev.)	22%
1/4	60	45-70	Film Stripping	25% Max.	None
4	26	5-30	Cleanness	75% Min.	87%
8	4	0-10			
16	2	0-5			
200	1	0-2			

TABLE 2

Temperatures

Time	Pavement		Air		Mix
	Sun	Shade	Sun	Shade	
8:30 A.M.	--	70°F	--	72°F	70°F
9:00	--	--	--	75°F	--
9:30	85	82	84	82	--
10:00	--	80	85	82	80
10:30	--	82	88	84	--
11:00	--	86	88	86	--
1:30 P.M.	--	100	--	92	--
5:30 P.M.	--	96	--	84	--

TABLE 3

Approximate Concentrations

Hot Mix vs Cold Mix Asphalts

Calculated from Integrated Nephelometer Readings

Measured Down wind	Hot Mix	Cold Mix
General Plant Operation	Very high	Very high
Loading Plant to Truck (Approx. 50-100' dw)	1.5 $\mu g/m^3$*	-0- **
Paving Operations (Approx. 50-100' dw)	0.77 $\mu g/m^3$	0.054⊗ $\mu g/m^3$

Special Conditions Measured

Direct reading from hot mix load 2.9 $\mu g/m^3$

Down wind reading from choker coat .49 $\mu g/m^3$

*Micrograms per cubic meter

⊗This reading is due to using a heated screed on the paver during operation even with cold mix.

**No visible emissions from mix when loading truck from plant or from truck to paver.

TABLE 4

Field Sample Test Results

Sta. No.	Type Emul.	Stability* 0-Hr. RT	Stability* 4-Hr. 140°	Stability* 24-Hr. 140°	Stability* 100 Hr. 140°	Cohesion* 0-Hr. RT	Cohesion* 4-Hr. 140°	Cohesion* 24-Hr. 140°	Cohesion* 100-H 140°
1+50 WB	CMS2H**	--	--	--	--	55	40	40	307
7 EB	"	--	--	--	--	60	35	65	240
10 Ctr.	"	--	--	--	--	45	35	55	210
13 WB	"	--	--	--	--	87	50	60	170
25 WB	"	--	--	--	--	102	52	63	190
18 Ctr.	CSS1H***	30	32	35	32	142	240	185	158
26 EB	"	27	34	34	33	104	210	175	157
32 WB	"	32	32	36	38	100	230	205	123
35 EB	"	28	30	35	31	135	247	180	175

*Specimens were compacted with a 40,000 lb. static load prior to curing. Curing was performed at 140°F. Testing at 0 hours was performed at room temperature. All other testing was performed at 140°F.
**Open Graded
***Dense Graded

TABLE 5

Field Sample Test Results

Sta. No.	Sample Position	Type Emul.	CALIF. HOT EXTRACTION % ASP	Moist.	1/2	3/8	4	8	16	30	50	100	200
1+50	Paver	CMS2H*	3.7	2.4	100	99	23	4	3	2	2	1	1
WB	Street	CMS2H	4.2	2.2	100	99	26	3	2	1	1	1	1
7	Paver	CMS2H	3.5	2.3	100	99	33	6	2	2	1	1	1
EB	Street	CMS2H	4.6	1.6	100	100	27	6	2	1	1	1	1
10	Paver	CMS2H	3.4	2.2	100	99	21	3	2	1	1	1	1
Center	Street	CMS2H	5.2	1.9	100	99	25	2	1	1	1	1	1
13	Paver	CMS2H	3.5	2.5	100	99	22	4	2	2	2	1	1
WB	Street	CMS2H	4.3	2.3	100	99	26	4	2	2	1	1	1
25	Paver	CMS2H	3.4	2.5	100	99	32	6	3	2	2	2	2
WB	Street	CMS2H	4.1	2.4	100	99	19	4	2	2	2	2	1
18	Paver	CSS1H**	4.3	8.6	99	84	55	40	26	18	12	8	6
Center	Street	CSS1H	3.8	7.8	98	76	46	35	24	17	12	8	6
26	Paver	CSS1H	3.8	7.9	98	77	49	38	26	18	13	9	6
EB	Street	CSS1H	4.2	6.6	96	73	45	35	24	17	12	8	6
32	Paver	CSS1H	3.9	8.2	98	79	50	38	27	20	15	11	7
WB	Street	CSS1H	5.1	7.6	98	82	60	39	28	20	12	11	8
35	Paver	CSS1H	4.2	8.3	100	79	51	39	27	19	12	9	6
EB	Street	CSS1H	***	7.3	100	70	48	36	26	18	10	8	6

* Open Graded
** Dense Graded
*** Lab Testing Error

TABLE 6

RECOVERED ASPHALT PROPERTIES

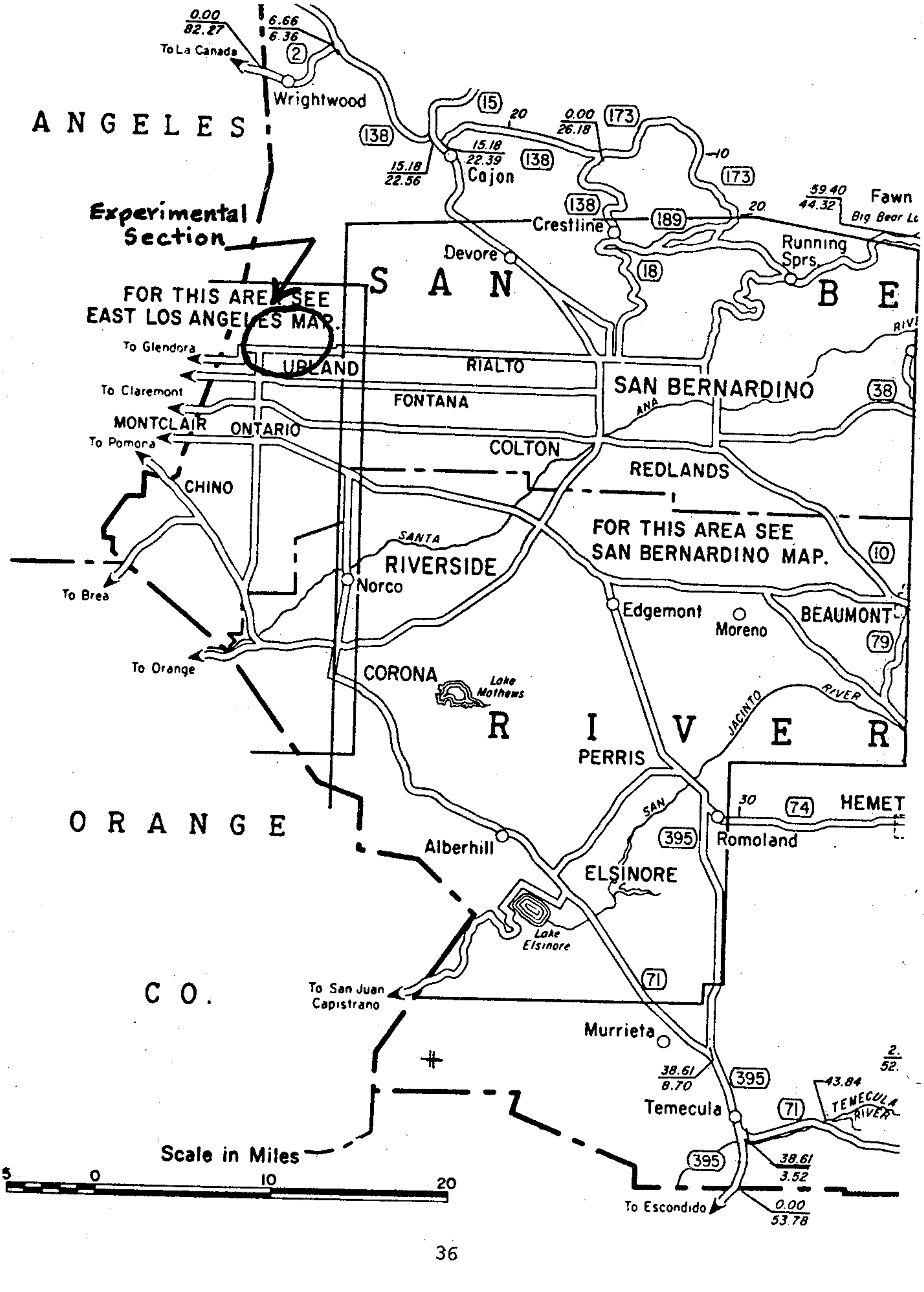
Open Graded Mix

Location	Emulsion		Penetration		Softening Point		Ductility	
Station	Type	%	7 Day	1 Year	7 Day	1 Year	7 Day	1 Year
1+50 WB	CMS-2H	7.0	40	23	128	147	150	100+
7+00 EB	CMS-2H	6.5	32	18	132.5	146	150	100+
10+00 Ctr	CMS-2H	6.5	25	14	136	153	150	43
13+00 WB	CMS-2H	7.0	25	15	137	153	150	28
25+00 WB	CMS-2H	6.5	26	19	138	152	150	45
Average of Recovered Penetration			30	18				

Dense Graded Mix

Location	Emulsion		Penetration		Softening Point		Ductility	
Station	Type	%	7 Day	1 Year	7 Day	1 Year	7 Day	1 Year
18+00 Ctr	CSS-1H	8.0	54	20	122	130	150	100+
26+00 EB	CSS-1H	8.0	46	15	123	151	150	100+
32+00 WB	CSS-1H	8.0	33	21	131	146	150	100+
35+00 EB	CSS-1H	8.0	33	27	130.5	145	150	100+
Average of Recovered Penetration			42	21				

Exhibit 1



ANGELES
Experimental Section
FOR THIS AREA SEE EAST LOS ANGELES MAP.
SAN BE
RIVER
ORANGE CO.
To La Canada
Wrightwood
0.00
82.27
6.66
6.36
15.18
22.56
15.18
22.39
0.00
26.18
Cajon
Crestline
Devore
Fawn
Big Bear Lc
Running Sprs.
59.40
44.32
To Glendora
To Claremont
To Pomona
MONTCLAIR
ONTARIO
UPLAND
RIALTO
FONTANA
SAN BERNARDINO
COLTON
REDLANDS
CHINO
To Brea
To Orange
SANTA ANA
RIVERSIDE
Norco
CORONA
Lake Mathews
FOR THIS AREA SEE SAN BERNARDINO MAP.
Edgemont
Moreno
BEAUMONT
PERRIS
JACINTO RIVER
HEMET
Romoland
Alberhill
ELSINORE
Lake Elsinore
To San Juan Capistrano
Murrieta
Temecula
TEMECULA RIVER
38.61
8.70
38.61
3.52
43.84
0.00
53.78
To Escondido
Scale in Miles
5 0 10 20

PLACEMENT OF COLD ASPHALTIC EMULSION MIXTURES

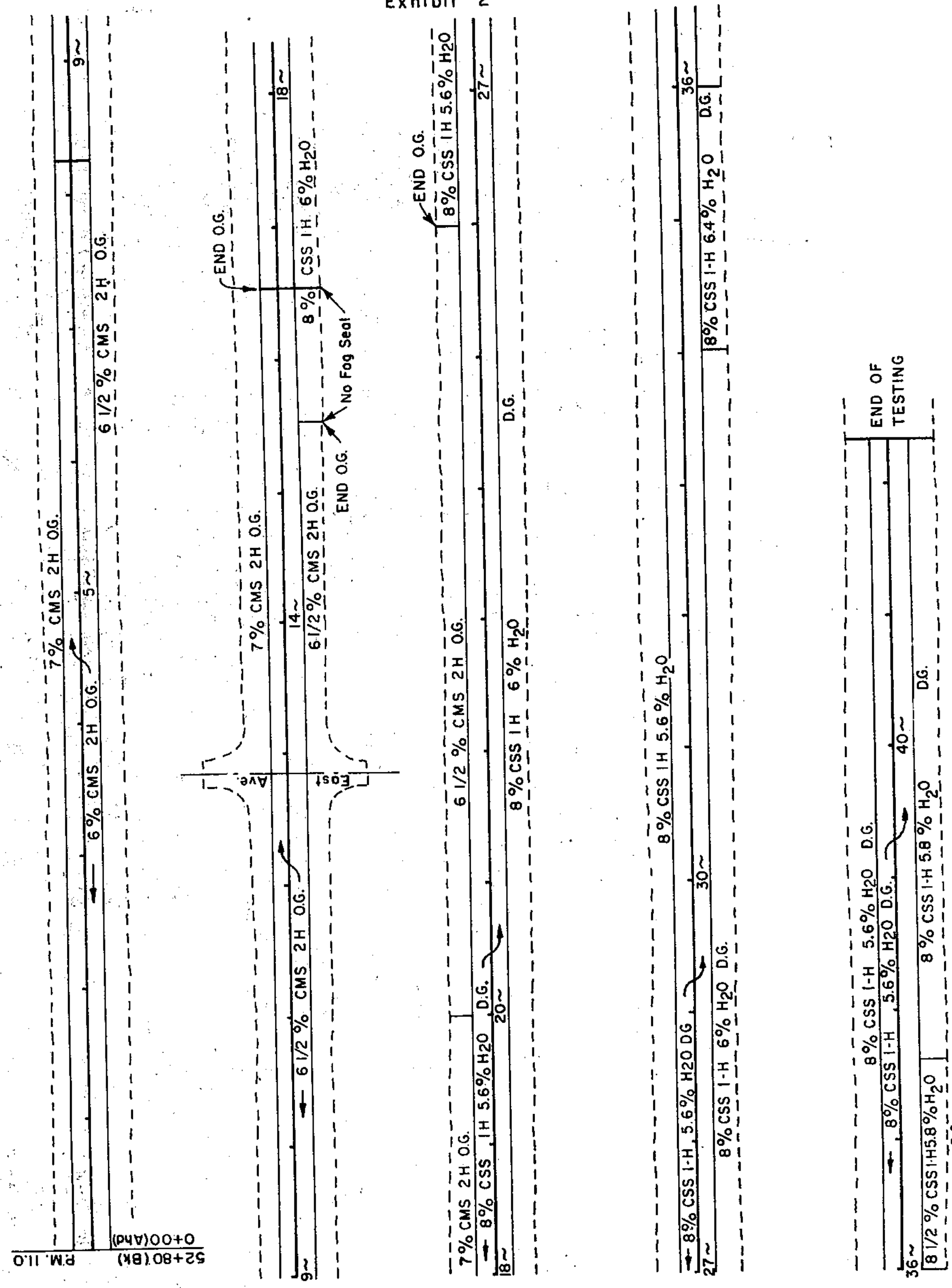
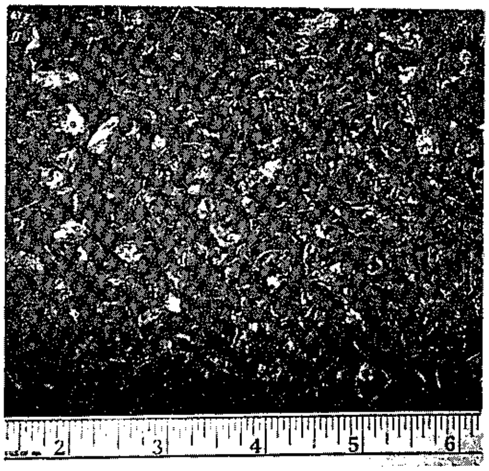
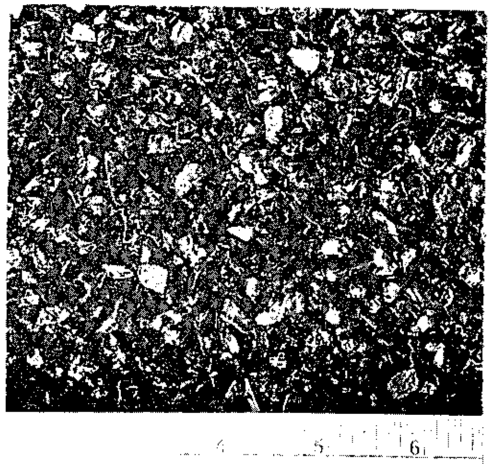


Exhibit 3

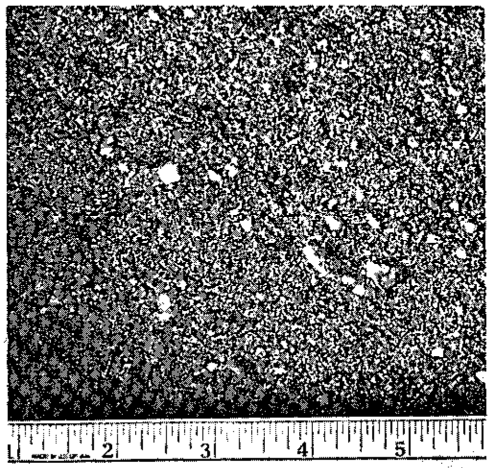
Open Graded Mixture (3/8 x #6)
Texture Photos
Station 0+20 - Section A - Position 2



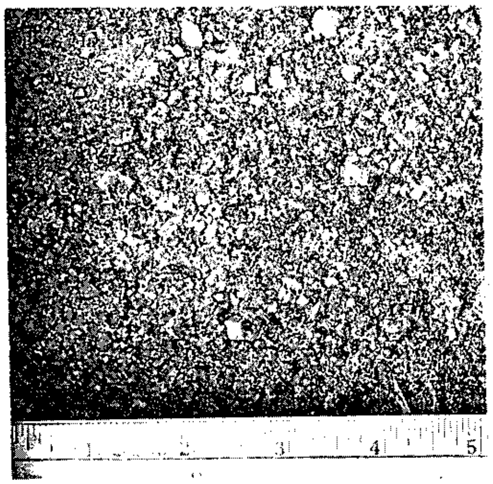
After Placing
(1)



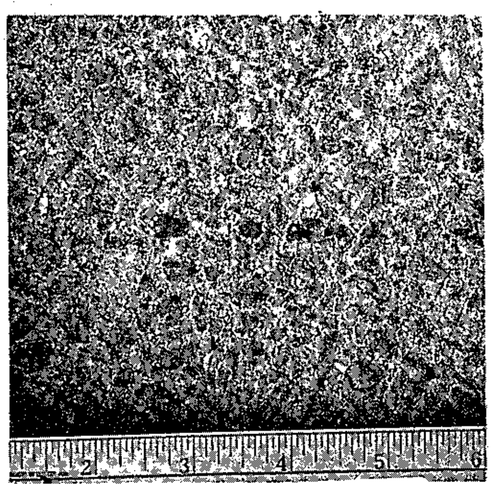
After Breakdown Roll
(2)



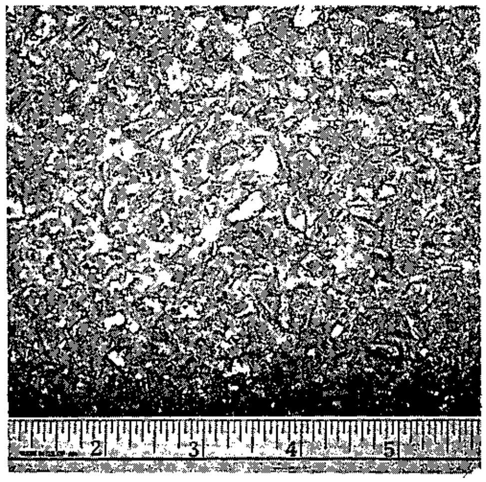
After Applying Sand
Choker
(3)



After Rolling Sand
Choker
(4)



24 Hrs. of Traffic
(5)



90 Days of Traffic
(6)

Exhibit 4

DENSE GRADED MIXTURE
Texture Photos
Station 26 - Section E - Position 2

Before Breakdown
Rolling
(1)

After Breakdown
Rolling
(2)

After 24 Hrs. Traffic
(Before Fog Seal)
(3)

After 90 Days

(4)

Exhibit 5

VARIATIONS IN ASPHALT CONTENT

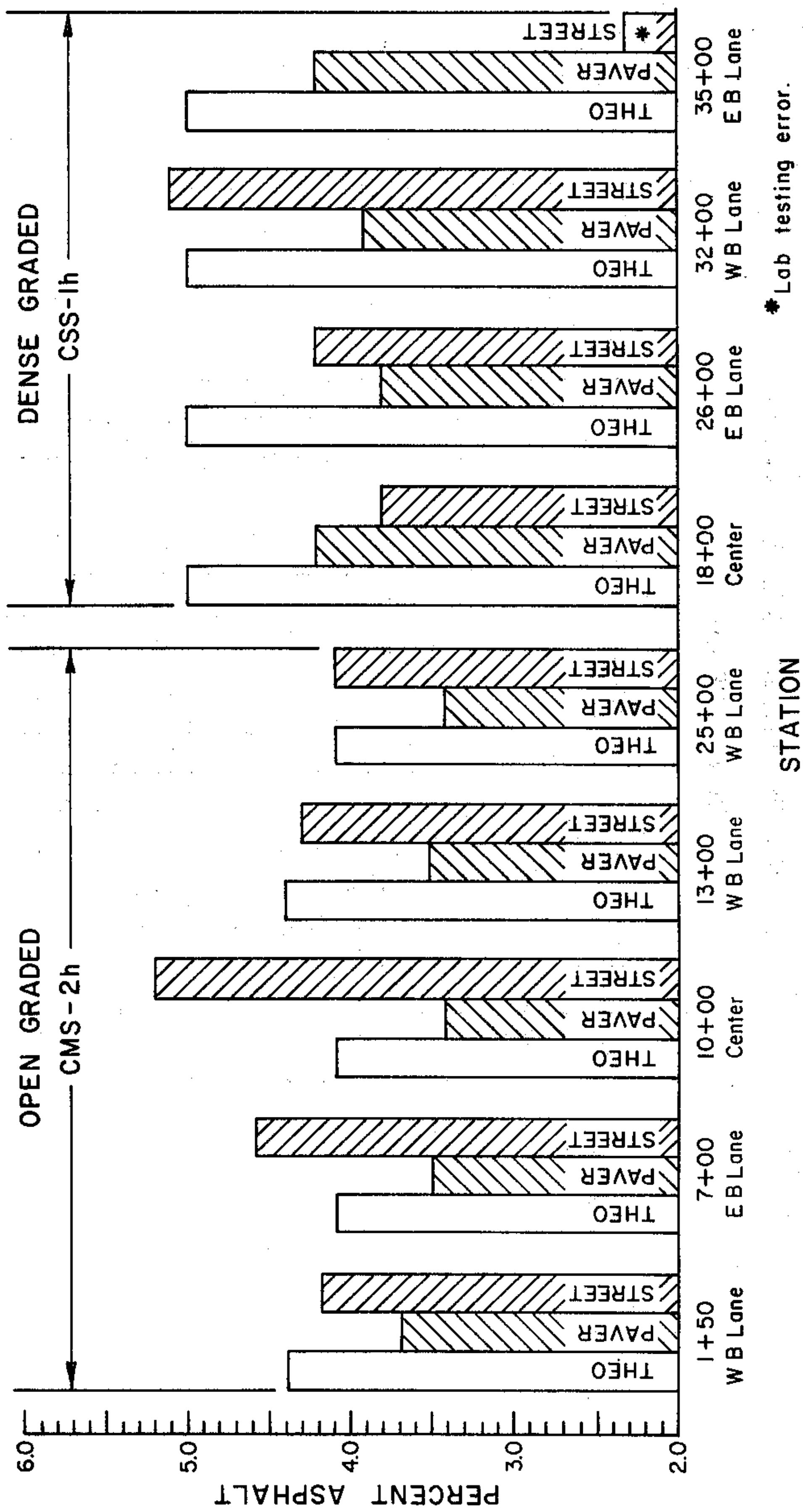
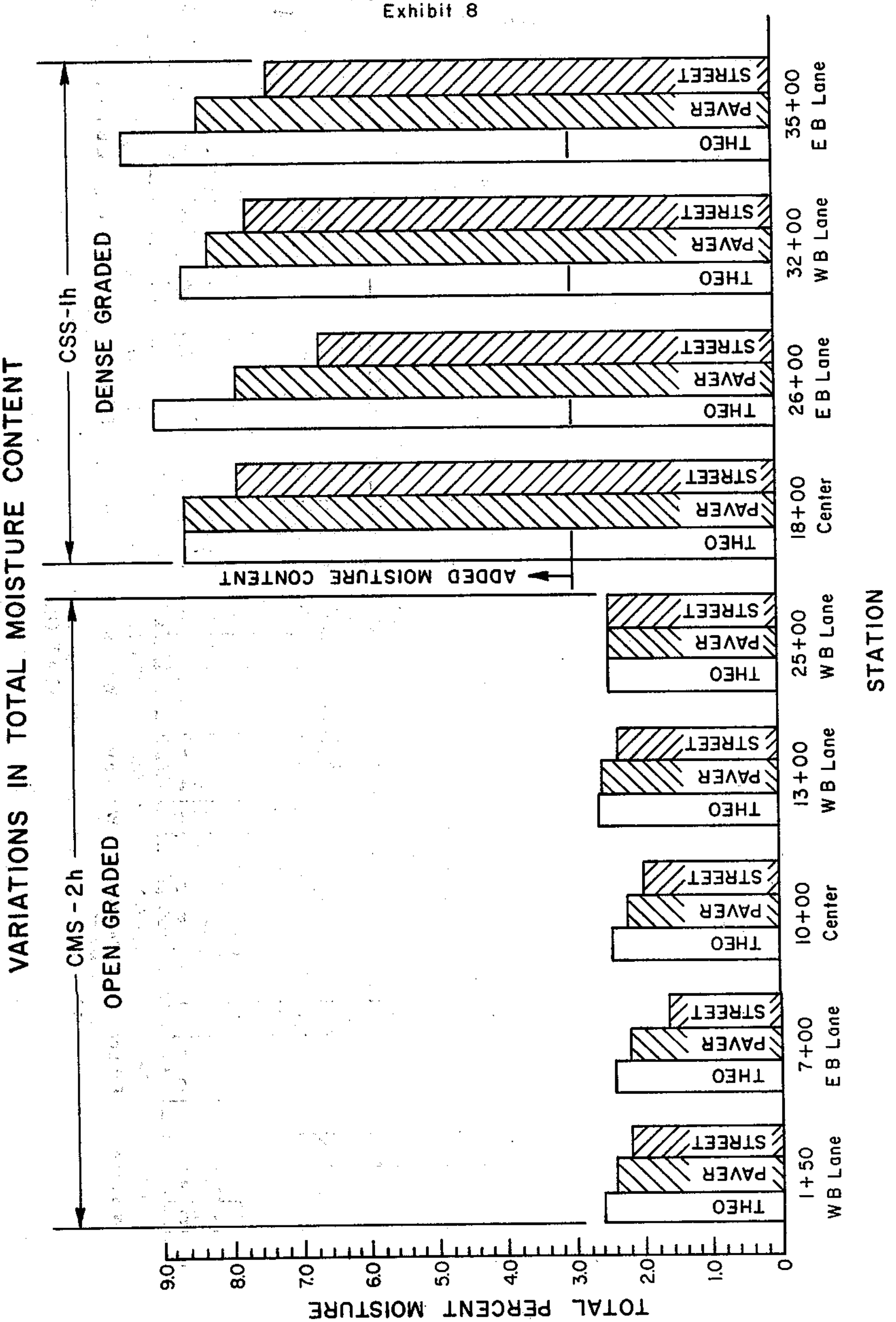


Exhibit 8



VARIATIONS IN TOTAL MOISTURE CONTENT
CMS-2h
OPEN GRADED
CSS-1h
DENSE GRADED
ADDED MOISTURE CONTENT
THEO
PAVER
STREET
1+50 WB Lane
7+00 EB Lane
10+00 Center
13+00 WB Lane
25+00 WB Lane
18+00 Center
26+00 EB Lane
32+00 WB Lane
35+00 EB Lane
STATION
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
TOTAL PERCENT MOISTURE